Implementing CIDOC CRM Search Based on Fundamental Relations and OWLIM Rules

Vladimir Alexiev, PhD, PMP
Data and Ontology Management Group
Ontotext Corp

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Presentation Outline

- Background and significance of CIDOC CRM
- Fundamental Concepts and Relations
- Example: Thing from Place: definition, graphical (network representation), SPARQL query
- Corrections and rationalization of FRs
- Inverses, Transitive properties, no Reflexive closure
- Parallel-Serial networks, decomposing a FR into sub-FRs, implementing with RDFS and OWL
- OWLIM and OWLIM Rules
- FR Implementation, Performance
Ontotext Cultural Heritage Projects/Clients

- Clients: UK, KR, SE, NL, BG, US

The National Archives  Yale Center for British Art

British Museum  de Bibliotheek

- Research projects executed by Ontotext

Presto Space  MOLTO  Research Space  Europeana

- Projects using OWLIM: EU, PL, JP

Charisma  3D-Coform  MNW  NII  LODAC
CIDOC CRM

- Created by International Committee for Documentation (CIDOC) of International Council of Museums (ICOM)
  - More than 10y of development, official standard ISO 21127:2006
  - Available at http://www.cidoc-crm.org/
  - Maintained by CRM SIG, crm-sig@ics.forth.gr

- Provides a common semantic framework to which any CH data can be mapped
  - Intended to promote shared understanding of CH data and a "semantic glue" to mediate between different CH sources
  - Few classes (82) and properties (142); quite expressive because it is abstract
  - Original focus: history, archaeology, cultural heritage (CH)
  - Used in various projects, including libraries, archives, museums
Importance of CRM

- CIDOC CRM can **map and subsume** various domain specific standards, thus allowing to compare, unify and inter-map them
  - E.g. influenced LIDO (events), EDM (subjects, events), mapped EAD, mapped UNIMARC, created FRBR as ontology (FRBRoo), etc

- Everything is connected... at the community (human) and technical (Semantic Web) levels

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Gordon Dunsire, U Strathclyde
Ontotext CRM Experience

- FP7 MOLTO: museum data is based on CRM
  - Multilingual Online Translation. Knowledge infrastructure, interoperability between natural language and structured queries,
  - Museum object descriptions in 15 languages. Gotehnburg Museum case

- ResearchSpace project of the British Museum is based on CRM
  - Advising British Museum and Yale Center for British Art on representing their collections in CRM

- Providing feedback and contributing to RDF definition of CRM

- Implementing CRM search based on Fundamental Relations
CIDOC CRM SEARCH
Fundamental Concepts and Relations (FC, FR)

- CRM data is usually represented in semantic web format (RDF) and comprises complex graphs of nodes and properties.
  - How can a user search through such complex graphs? The number of possible combinations is staggering.

- New Framework for Querying Semantic Networks (FORTH TR419, 2011)
  - "Compresses" the semantic network by mapping many CRM entity classes to a few "Fundamental Concepts" (FC): **Thing, Place, Actor, Event/Time, Concept/Type**
  - Maps whole networks of CRM properties to fewer "Fundamental Relations" (FR)
  - FC and FRs serve as a "search index" over the CRM semantic web and allow the user to use a simpler query vocabulary.
    - FR categories include: **type, part, from/generator, similar/same, met, refers/about, borders/overlaps, by** and some of their inverses
    - Matrix declares 114 FRs (18 of them very similar) and 18 "specialization FRs" (e.g. Thing **acquired at** Place is specialization/part of Thing **from** Place)

- Fundamental Categories and Relationships for intuitive querying CIDOC-CRM based repositories (FORTH TR-429, Apr 2012, 153 pages)
  - Defines FRs over all combinations of FCs
<table>
<thead>
<tr>
<th>Domain (select)</th>
<th>Thing</th>
<th>Actor</th>
<th>Place</th>
<th>Event</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thing</strong></td>
<td>8.has met</td>
<td>8.has met</td>
<td>9.refers to</td>
<td>9.refers to</td>
<td>5.from</td>
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<td></td>
<td>9.refers to or is about</td>
<td>5.from</td>
<td>10.is referred to at</td>
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<td>Created on</td>
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<td></td>
<td>10.is referred to by</td>
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<td>5.from</td>
<td>5.from</td>
<td>Created on</td>
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<tr>
<td></td>
<td>5.has part</td>
<td>5.has part</td>
<td>8.has met</td>
<td>8.has met</td>
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<tr>
<td></td>
<td>7.is similar or same with</td>
<td>7.is similar or same with</td>
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<tr>
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<td>4.is part of</td>
<td>4.is part of</td>
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<td>Created on</td>
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<tr>
<td><strong>Actor</strong></td>
<td>8.has met</td>
<td>4.is member of</td>
<td>8.has met</td>
<td>8.has met</td>
<td>5.from</td>
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<tr>
<td></td>
<td>6.is owner or creator of</td>
<td>6.is owner or creator of</td>
<td>8.has met</td>
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<td>10.is referred by</td>
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<td>8.has met</td>
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<tr>
<td><strong>Place</strong></td>
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<td>8.has met</td>
<td>4.is part of</td>
<td>9.refers to</td>
<td>5.from</td>
</tr>
<tr>
<td></td>
<td>6.is origin of</td>
<td>6.is origin of</td>
<td>10.is referred by</td>
<td>10.is referred by</td>
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<tr>
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<td>9.refers to or is about</td>
<td>9.refers to or is about</td>
<td>8.has met</td>
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<td>Created on</td>
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<td>11.borders or overlaps with</td>
<td>11.borders or overlaps with</td>
<td>8.has met</td>
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<td><strong>Event</strong></td>
<td>5. from</td>
<td>12.by</td>
<td>9.refers to or is about</td>
<td>9.refers to or is about</td>
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<td>6.is origin of</td>
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<td></td>
<td>created</td>
<td>destroyed</td>
<td>started</td>
<td>ended</td>
<td>Created on</td>
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<tr>
<td></td>
<td>destroyed</td>
<td>modified</td>
<td>has duration</td>
<td>has duration</td>
<td>Created on</td>
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</tbody>
</table>
Thing from Place: A Sample FR

All alternatives through which a Thing's origin can be related to Place a Thing (part of another Thing)* is considered to be "from" Place if it:

• is formerly or currently located at Place (that falls within another)*

• or was brought into existence (produced/created) by an Event (part of another)*
  – that happened at Place (that falls within another)*
  – or was carried out by an Actor (who is member of a Group)*
    • who formerly or currently has residence at Place (that falls within another)*
    • or was brought into existence (born/formed) by an Event (part of another)*
      that happened at Place (that falls within another)*

• or was Moved to/from a Place (that falls within another)*

• or changed ownership through an Acquisition (part of another)*
  – that happened at Place (that falls within another)*
FC70_Thing --(P46i_forms_part_of* | P106i_forms_part_of* | P148i_is_component_of*)-> FC70_Thing:
{FC70_Thing --(P53_has_former_or_current_location | P54_has_current_permenent_location)-> E53_Place:
{E53_Place --P89_falls_within*-> E53_Place}OR FC70_Thing --P92i_was_brought_into_existence_by-> E63_Beginning_of_Existence:
{E63_Beginning_of_Existence --P9i_forms_part_of*-> E5_Event:
{E5_Event --P7_took_place_at-> E53_Place:
{E53_Place --P89_falls_within*-> E53_Place}OR E7_Activity --P14_carried_out_by-> E39_Actor:
{E39_Actor --P107i_is_current_or_former_member_of* -> E39_Actor:
{E39_Actor --P74_has_current_or_former_residence -> E53_Place:
{E53_Place --P89_falls_within*-> E53_Place}OR E39_Actor --P92i_was_brought_into_existence_by-> E63_Beginning_of_Existence:
{E63_Beginning_of_Existence --P9i_forms_part_of*-> E5_Event:
{E5_Event --P7_took_place_at-> E53_Place:
{E53_Place --P89_falls_within* -> E53_Place}}}}}}}}OR E19_Physical_Thing --P25i_moved_by-> E9_Move:
{E9_Move --(P26_moved_to | P27_moved_from)-> E53_Place:
{E53_Place --P89_falls_within*-> E53_Place}OR E19_Physical_Object --P24i_changed_ownership_through-> E8_Acquisition:
{E8_Acquisition --P9i_forms_part_of*-> E5_Event:
{E5_Event --P7_took_place_at-> E53_Place:
{E53_Place --P89_falls_within*-> E53_Place}}}
Although defined as a tree of property paths, the FR is better depicted as a network through a simple merge of leaf-level nodes.
select ?t ?p2 {
?t a FC70_Thing. ?t (P46i_forms_part_of* | P106i_forms_part_of* | P148i_is_component_of*) ?t1.
 {?t1 (P53_has_former_or_current_location | P54_has_current_permanent_location) ?p1}
 UNION
 {?t1 P92i_was_brought_into_existence_by ?e1. ?e1 P9i_forms_part_of* ?e2.
  {?e2 P7_took_place_at ?p1}
  UNION
  {?e2 P14_carried_out_by ?a1.
   {?a1 P107i_is_current_or_former_member_of* ?a2.
    {?a2 P74_has_current_or_former_residence ?p1}
    UNION
    {?a2 P92i_was_brought_into_existence_by ?e3. ?e3 P9i_forms_part_of* ?e4.
     {?e4 P7_took_place_at ?p1}
  }}
} UNION
 {?t2 P25i_moved_by ?e5. ?e5 (P26_moved_to | P27_moved_from) ?p1}
 UNION
 {?t2 P24i_changed_ownership_through ?e6.
  {?e6 P9i_forms_part_of ?e7. ?e7 P7_took_place_at ?p1}.
?p1 P89_falls_within* ?p2}

- This query is very complex and expensive, especially when you need to combine with other FRs into composite queries.
Thing from Place: Corrections and Rationalization

- Allowed paths of mixed properties (e.g. P46i,P106i) at the beginning
- Allowed a loop P9i* at E9 (Move forms part of a bigger event) by merging the nodes E8, E9, and the second E63
- Allowed P10_falls_within in addition to P9i_forms_part_of (after consultation with the original authors)
- Skipped P26,P27: they are subproperties of P7, so it's enough to check for P7
  - Simpler than the original, but still quite complex
Inverses, Transitive properties

• Most CRM properties have inverse (symmetric properties are their own inverse)
  – FRs use CRM properties in both directions: forward (e.g. P53_has_former_or_current_location) and inverse (P24i_changed_ownership_through)
  – It's useful to rely on owl:inverseOf inferencing

• FRs use transitive closure to traverse "part" hierarchies
  – CRM has physical object parts, conceptual object parts, sub-places, sub-events
  – CRM scope notes suggest 14 properties (and inverses) should be transitive: P9 P10 P46 P86 P88 P89 P106 P114 P115 P116 P117 P120 P127 P148.
  – In addition to these "atomic" properties, disjunctions of properties often also need to be declared as transitive.
  – It's useful to rely on owl:TransitiveProperty inferencing.
FRs often use reflexive-transitive closure (0 repetitions)
  - E.g. Thing from Place: can relate directly to a place, or to any of its super-places
  - We have opted not to use reflexive closure in the implementation, since it would generate a lot of trivial facts (self-loops).
  - We use disjunction instead: the iterated property is applied 0 times in the first disjunct, and $n$ times in the second

FRs are defined mostly as parallel-serial networks of properties
  - Can be seen from the SPARQL Property Path constructs and is explained below
Decomposing Thing from Place into sub-FRs

# self-loops and simple disjunctions

- $FRT_{46i \_ 106i \_ 148i} := (P46i|P106i|P148i)^+\$
- $FRT_{9i \_ 10} := (P9|P10)^+\$
- $FRT_{107i} := P107i^+\$
- $FRT_{89} := P89^+\$
- $FRX_{53 \_ 54} := (P53|P54)\$
- $FRX_{24i \_ 25i} := (P24i|P25i)\$

# growing fragments

- $FRX_{92i} := P92i | P92i/FRT_{9i \_ 10}\$
- $FRX_{92i \_ 14} := FRX_{92i}/P14 | FRX_{92i}/P14/FRT_{107i}\$
- $FRX_{FC70 \_ E8 \_ 9 \_ 63} := FRX_{92i \_ 14}/P92i | FRX_{24i \_ 25i}\$
- $FRX_{FC70 \_ E8 \_ 9 \_ 63 \_ P7} := FRX_{FC70 \_ E8 \_ 9 \_ 63}/P7 | FRX_{FC70 \_ E8 \_ 9 \_ 63}/FRT_{9i \_ 10}/P7\$
- $FRX_{7} := FRX_{53 \_ 54} | FRX_{FC70 \_ E8 \_ 9 \_ 63 \_ P7} | FRX_{92i \_ 14}/P74 | FRX_{92i}/P7\$
- $FRX_{7 \_ P89} := FRX_{7} | FRX_{7}/FRT_{89}\$
- $FR7 := FRX_{7 \_ P89} | FRT_{46i \_ 106i \_ 148i}/FRX_{7 \_ P89}\$

- "Sub-FRs" are auxiliary relations used to build up the final FR
- The numbering comes from CRM property and entity names
- Prefixes: FR: final result, FRT: transitive, FRX: non-transitive, FC70 or E: from/to that class
### Implementing Parallel-Serial with RDFS and OWL

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Construct</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>inverse</td>
<td>prop := ^prop1</td>
<td>prop1 owl:inverseOf prop2.</td>
</tr>
<tr>
<td>parallel</td>
<td>prop := prop1|prop2</td>
<td>prop1 rdfs:subPropertyOf prop.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prop2 rdfs:subPropertyOf prop.</td>
</tr>
<tr>
<td>serial</td>
<td>prop := prop1/prop2</td>
<td>prop owl:PropertyChainAxiom (prop1 prop2).</td>
</tr>
<tr>
<td>transitive</td>
<td>prop := prop1+</td>
<td>prop1 rdfs:subPropertyOf prop.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prop owl:TransitiveProperty</td>
</tr>
<tr>
<td>reflexive-transitive</td>
<td>prop := prop1 prop2*</td>
<td>Converted to the following:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prop := prop1</td>
</tr>
</tbody>
</table>

- 3 RDFS and OWL constructs are sufficient to implement parallel-serial networks: `subPropertyOf`, `TransitiveProperty`, `PropertyChainAxiom`
  - In OWLIM, they are implemented using Rules

- So can't we stick to these constructs and not use OWLIM Rules at the application level?
Type Checking and Conjunctive Properties

- The original FR definition supposes type checks for every node (FC70, E63...), e.g.:
  \[ ?x \text{ FR7\_from\_place } ?y := ?x \text{ a FC70\_Thing}; \text{ FR7 } ?y; ?y \text{ a E53\_Place}. \]

- In many cases type checks can be skipped since they are implied by property ranges (e.g. P53 P54 P7 P47 P89 imply E53)

- In other cases type checks are required in the middle of a network. E.g. "Thing about X" is a family of FRs, where X is Thing, Place, Actor, Event

- For this we'd need conjunctive properties, which are not part of OWL2
  - OWL RL can be extended with role conjunctions without restrictions or increase in complexity
  - There is a proposal to include conjunctive properties in OWL 3
OWLIM

• A commercial semantic repository by Ontotext
  – Incremental assert and retract
  – High-performance: fully-materializing, replication cluster, strong benchmark results, good concurrent query response, cloud deployment

• Used in some landmark semweb projects
  – Runs BBC Sports, World Cup 2010 and the Olympics 2012
  – linkedlifedata.com semantic warehouse used by top-20 pharmaceuticals

• Quite a following in cultural heritage
  – The National Archives, The British Museum, Yale Center for British Art
  – FP7: 3D COFORM, CHARISMA, MOLTO
  – LOD.AC, Polish Digital National Museum
OWLIM Rules

- Allow simple unification and in/equality constraints
  - OWLIM implements OWL2 QL and RL using these rules
  - Custom rules are treated just like OWL (system) rules
  - E.g. sub-property, transitive, inverse reasoning:
    \[ x \text{ p1} y; p2 <\text{rdfs:subPropertyOf}> p2 \text{ [Constraint p1!=p2]} \Rightarrow x \text{ p2} y \]
    \[ p <\text{rdf:type}> <\text{owl:TransitiveProperty}>; x \text{ p} y; y \text{ p} z \Rightarrow x \text{ p} z \]
    \[ p1 <\text{owl:inverseOf}> p2; x \text{ p1} y \Rightarrow y \text{ p2} x \]
    \[ p1 <\text{owl:inverseOf}> p2; x \text{ p2} y \Rightarrow y \text{ p1} x \]

- Advantages:
  - Speed: forward-chaining & full materialization (translated to Java bytecode for speed), so query answering is very fast
  - "Reversible": when a triple is retracted, all consequences with no other support are retracted

- Disadvantages
  - Inflexible: if rules are changed, the repository needs to be reloaded.
    (Better implement generic rules that work on TBox assertions about properties.)
  - Proprietary to OWLIM
    (Ontotext is considering proposed standard rule languages in future versions)
  - Don't support real negation (e.g. instance is not of a given class or its super-classes)
Once the FR is decomposed to sub-FRs, implementation is straightforward. E.g. this sub-FR is implemented as:

FRT_46i_106i_148i := (P46i|P106i|P148i)+

\[ x \xleftarrow{\text{crm:P46i_forms_part_of}} y \Rightarrow x \xleftarrow{\text{rso:FRT_46i_106i_148i}} y \]
\[ x \xleftarrow{\text{crm:P106i_forms_part_of}} y \Rightarrow x \xleftarrow{\text{rso:FRT_46i_106i_148i}} y \]
\[ x \xleftarrow{\text{crm:P148i_is_component_of}} y \Rightarrow x \xleftarrow{\text{rso:FRT_46i_106i_148i}} y \]

\texttt{<rso:FRT_46i_106i_148i> <rdf:type> <owl:TransitiveProperty>}

- Important to extract common sub-FRs between FRs, to facilitate reuse

We implemented 11 FRs of Thing:
- refers to or is about Place; from Place; is/was located in Place
- has met Actor; by Actor
- refers to or is about Event; has met Event
- is made of Material; is/has Type; used technique; identified by Identifier

Use 44 CRM properties. Took 86 rules, 10 axioms, 26 sub-FRs
Bug in "Thing has met Event"

- **Acquisition**
  - Often modeled as E8_Acquisition (changes owner), E10_Transfer_of_Custody (changes keeper), E80_Part_Removal (removes object from old collection), E79_Part_Addition (adds object to new collection)
  - An event at which meet: object, buyer, seller, old collection, new collection
  - Object (E22_Man-Made_Object) is P46i_forms_part_of old collection before acquisition (E78_Collection) and new collection after acquisition (E78_Collection)

- **FC70_Thing --FR12_was_present_at-> E5_Event :=**
  - FC70_Thing --(P46i_forms_part_of | P106i_forms_part_of | P148i_is_component_of)* -> FC70_Thing --P12i_was_present_at-> E5_Event:
  - E5_Event --P9i_forms_part_of*-> E5_Event

- **Causes all objects in a collection to have met (witnessed) the addition of all other objects in the collection!**
  - For new objects: logically impossible. For old objects: useless
  - Quadratic growth of data, exponential slowdown of data loading
  - BM has 1.5M objects in its collection, so the slowdown is unbearable
How did this bug make me feel?

- Took a couple of hours of debugging triples to diagnose

- Inference is powerful, but may expose unintended consequences

- **Karakondjul** (Greek and Bulgarian): poltergeist, house troll
Performance

• A concern was expressed that materializing sub-FR triples may increase the repository size too much and slow it down?

• Small repository of RKD data
  – 11 Rembrandt paintings: 1.5M triples, including 0.5M object triples (complex data about each painting, researches, documents, etc) and 1M thesaurus triples (people, places, etc)
  – FRs added only 25.8k triples, which is 1.7% of the total data or 5.1% of the object data → no perceptible slowdown

• Medium repository of BM data
  – Over 150k BM objects, about 20M triples
  – FR searches show no noticeable slow-down
  – Pending: all 1.5M BM objects

• OWLIM performs well on 10s B triples
  – Examples: linkedlifedata.com (public), The National Archives, BBC
  – So increases in the number of triples up to 50% are trivial

• Compare the raw SPARQL query on slide 13
Thanks for your attention!

- Questions/Discussion

- Contact: vladimir.alexiev@ontotext.com